Definition and Study of an Innovative Façade System Made of Independent Pre-vegetated and Water Storage Modules

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Abstract

This communication is a result of the SOS-Natura project, enshrined in the INNPACTO program from the Spanish Ministry of Science and Innovation. The overall objective of the project is developing a new green wall solution that enhances energy efficiency of the building throughout its life cycle. The project is led by the Spanish company Intemper S.L., involving Tecnalia, AmetsLab (Modular Architecture Eco-technological S.L.) and the Universidad Politécnica de Madrid (UPM).

The Project proposes a green building envelope system made up of a group of pre-vegetated independent detachable panels. These panels or modules include the necessary green substratum for growing plants. To water with any additional fertilizer is not necessary because of the water tank located in the bottom part of every single panel or module. The water storage tank incorporated in the wall system allows that every different vegetable species could absorb water according to their necessities. It results on remarkable water saving and a homogeneous growing of the plants.

Simulations made with ENVI-met software allow modeling the urban microclimate from a starting point of interaction of the land surface, wind and vertical surfaces. They demonstrate that green water storage façade achieve a higher reduction of CO_2 in comparison with tree-lined street solutions. The effect is amplified in narrow streets – those with a relation between width and length under 1. Analysis run during summer period indicates that the use of green water storage façade allows reducing temperature in comparison with a tree-lined street.

This communication also details de results obtained using DesignBuilder software for energy simulations. The wall solution allows homogeneous inside comfort temperatures which tend to cool the ambient, in summer time, in comparison with other wall solutions as well as the previous advantages already mentioned. A cradle to gate life cycle assessment has been also performed.

1 Introduction

One of today's architectural challenges is the assumption of the "IEA's 450 Scenario" in which the International Energy Agency presented an alternative model for building construction [1]. The model is based on eco-innovation and promoting greater energy efficiency through the reduction of the environmental impact. Governments and professional associations around the world are trying to solve the problem of energy inefficiency of buildings, but the initiatives lose strength because building

envelopes are constructed using archaic techniques poorly adapted to the energy demands of nowadays. [2]
The research SOS-Natura project, Vegetated Architectural Solutions, assumes the challenge posed by the IEA and seeks to answer, by applying our own methodology of eco-innovation, the problems of energy efficiency and environmental impact in buildings envelopes. This research has developed a new system of pre-vegetated water storage panels for living walls that provide significant savings in water consumption compared to other green wall systems. It also offers an improvement for the interior comfort of the building.
The starting point of the project was the design of a plastic container which works both as substratum and plants container and water tank. It can be installed as the external layer of a multilayer façade being the visible and more innovative part of the façade system. The design process of the envelope system has been assisted by different tools such as computer simulation in different fields and a lyfe cycle analysis.

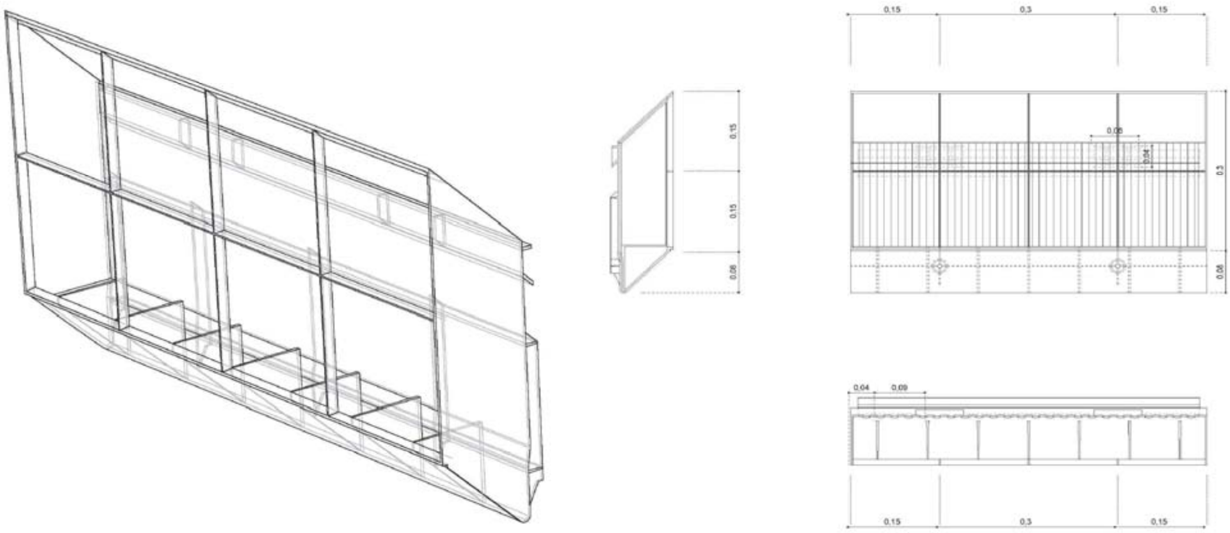

Figure 1: Perspective view and plans of the plastic module Naturpanel

The main objective of simulating the energy performance of the living wall panels system proposed is to quantify the energy savings generated for it, and to study the hygrothermal behavior of the system. Computer-assisted energy simulation software (properly validated and calibrated) has been used as a method of testing and as a complementary tool to empirical testing as well. It has established that this type of living wall panel offers a homogeneous solution that allows improving comfort temperatures inside buildings.
Solar radiation absorbed by building materials used for building envelopes has also a big influence the temperature distribution in urban areas [3]. The thermo-physical properties (solar albedo and emissivity infrared) of building materials have a strong impact on the energy balance of the cities. The street pavement and façades are the components most exposed to solar radiation which, in most cases, are materials with high absorptivity and high thermal capacity. These characteristics lead to what we know today as the effect of urban heat island and it is often significant in comfort conditions for arid climates with high levels of radiation.
Because of that, it is necessary to find solutions that improve these conditions, and green façades could be one of them. Urban vegetation could reduce the temperature of the materials and their infrared emissivity by solar absorption and evaporative cooling [4].

2 System description

2.1 Naturpanel module

The starting point of the project was the design of a plastic module called Naturpanel, which works both as the substratum and plants container and water tank. (Figure 1)
It can be installed as the external layer of a multilayer façade being the visible and more innovative part of the façade system.

2.2 Brief description of the façade system

The green façade is formed by means of an assembly of detachable pre-vegetated panels, wherein it is possible to meet the water needs of the entire façade through a tank included at the bottom part of each panel. In consequence, it is not necessary to water the panels. The façade do not require an individual irrigation installation for each of the panels, but rather it is only necessary to supply water to the upper panel for each of the columns forming the green façade. The whole façade finishing is formed by means of assembly panels in columns and rows.

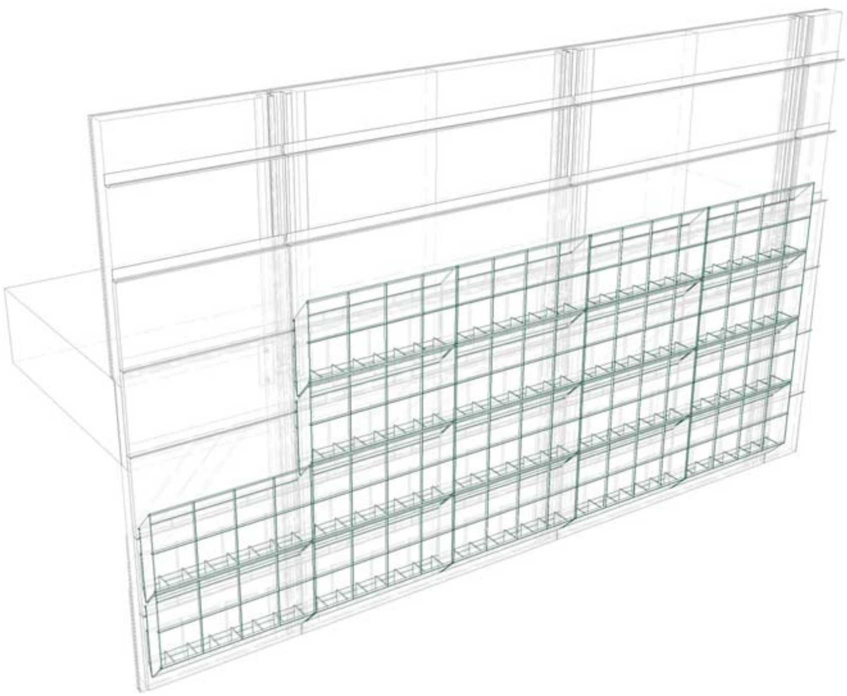

Figure 2: Green wall made up of Naturpanel modules.

Each panel can be individually replaced without needing to remove any adjacent panel since they are not conditioned by the irrigation networks which complicate the replacement of other similar panels which are nowadays in the market.
Once they are settled, the pre-vegetated and water storage modules are going to be the external layer of a multilayer façade for new buildings. They can also be used as a building retrofitting solution when settled over the external face of an existing façade.

3 Computer modeling

The computer simulation tool emerged as a design support tool that offers a cost reduction for research and for the building construction industry. This cost saving is obtained because the simulation allows us to characterize and calculate a complex system (and all its variations) in a setting and under certain boundary conditions, without incurring into the expenses that occurs with the traditional empirical test systems. [5]

3.1 Energy simulations & reference façade

We have proceeded to model a conventional semi-light façade typology with and without the new living wall panels under study, based on MoWiTT type tests designed by the Lawrence Berkeley laboratories at the University of California [6] [7],. This simulation has been set according to the constraints of each extreme orientation (North, South, East and West) in Madrid, in order to compare them with the empirical tests that are being performed by a monitoring group. The conclusions drown are helping to calibrate the simulation tool (Design Builder software). Because of being opaque walls, the guidelines vary very little in the final results, (Figure-3) but its study and analysis has helped the monitoring group to make the decisions at the experiment design level. The wall has been modeled with the data of a semi-light façade improved with the living wall module prototype, and has been simulated over a year in the four previously mentioned extreme orientations in the city of Madrid without energy input or cooling elements.

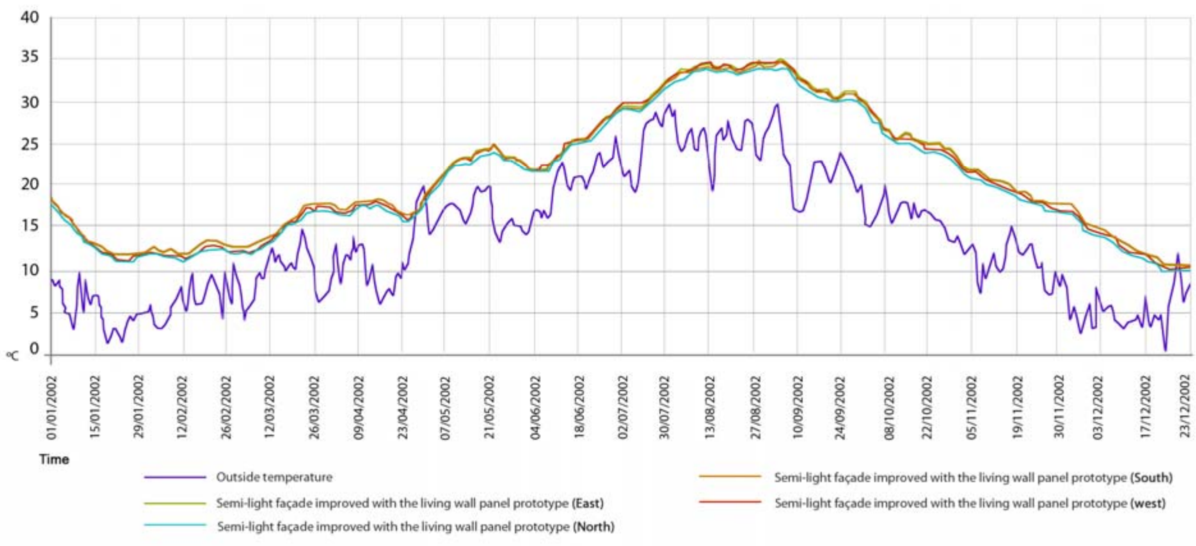

Figure 3: Thermal behavior inside an adiabatic box with only one non-adiabatic wall of the enclosure.

For façades including the living wall panel prototype, the thickness of the mineral wool insulation layer would be 9 cm, when an R value of 0.3 W / m·K is required. By contrast, for the same façade but without the living panel addition, the thickness of the mineral wool insulation should be 12.59 cm. This research shows that if we improve a semi-light multilayer façade composed of a mineral wool insulation with R value 0.031 W / m·K, by adding the living wall panel prototype, we will obtain a reduction of 3.59 cm of the necessary thermal insulation for the façade. This data have been obtained considering Madrid's climate conditions.

The energy simulation performed for the innovative façade system designed at the SOS-Nature project has detected more benefits. In computer simulations performed with free evolution of the system (without energy input or cooling elements considered), and in comparison to the semi-light facade of reference, improved with the living wall prototype subjected to summer test conditions in the city of Madrid, has determined that thermal comfort inside the building, using the living wall prototype, is stable and homogeneous, which may offer an improved of 5 ° C temperature with respect to not using the living wall prototype panel. (Figure 4) One of them has been modeled as a façade improved with the living wall panel prototype, and the other is the same facade but without the living wall panel. Both facades have been simulated from the 7th to the 14th of July, in Madrid, with south orientation.

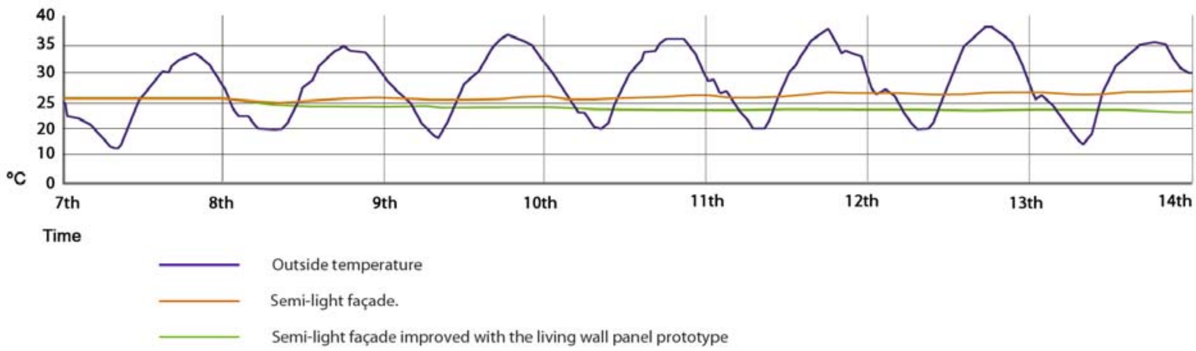

Figure 4: Comparison of the thermal behavior inside of two adiabatic boxes with only one non-adiabatic wall of the enclosure in each box in July 8th to 14th.

This improvement is mainly due to the ability of plants to regulate its surface temperature, providing a smaller temperature difference between the inner surface of the facade and the outside, but also due to the action of water evaporation from the water tank included in every module, and the shadow cast on the surface of plants.

3.2 Surface-plant-air interactions in urban environment

Considering the important role that vegetation plays in urban comfort, the objective of this part of the research has been analyzing the effects of green walls in the urban microclimate of Madrid in relation to different street morphologies with or without urban vegetation.

Different real ratios (height of building divided by width of street) were extracted from representative case studies of the city of Madrid where it was possible to incorporate green façades.

The wind direction is important for the human comfort as well as for the distribution of particulate matters. The orientation of the façades is an important parameter too. It varies due to incoming radiation into the building and absorption and / or transmission of the same through the different materials. Madrid has an average daily global solar radiation on a horizontal surface per year, from $16.6 \leq H < 18.0$ MJ/m2 and $4.6 \leq H < 5.0$ kWh/m2. Façades facing south receive high levels of radiation in winter and low levels in summer. The North façade is the one that receives less radiation. While the façades East and West receive higher radiation levels and because of that, these are the facades where green façade could be a good strategy.

Other factors affecting the thermal comfort for people staying in open spaces are temperature (K), relative humidity (%), and air movement (m/s). Madrid's climate is characterized by hot and dry summers with low relative humidity, which contrast with cold winters with moderately high moisture in air. Humidity is low in summer time and moderately high in winters. It is also important to consider daily fluctuation of temperature during summer time.

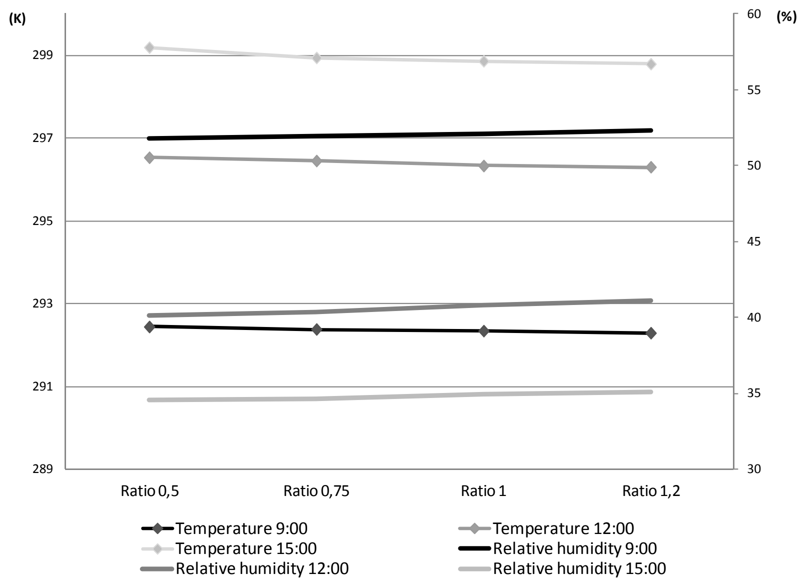

Figure 5. Comparison between temperature and relative humidity, during summer time, in a street with green façade, considering different ratios.

All the computer simulations have been performed considering summer conditions (in July) with Envimet V3.1. This software has some limitations, such as the area input file editor, so very simple and small street scenarios were considered: a two-building set with green façades (East and West) and different street ratios. The results should not be considered as absolute values or absolute differences but as trends.
Simulations can be analyzed for different periods of time and different urban morphologies as well (Figure 5). Urban comfort is bigger at the early hours of the day, when temperature values are lower and relative humidity is higher. The results tend to be higher the smaller the width of street is (ratios bigger than 1).

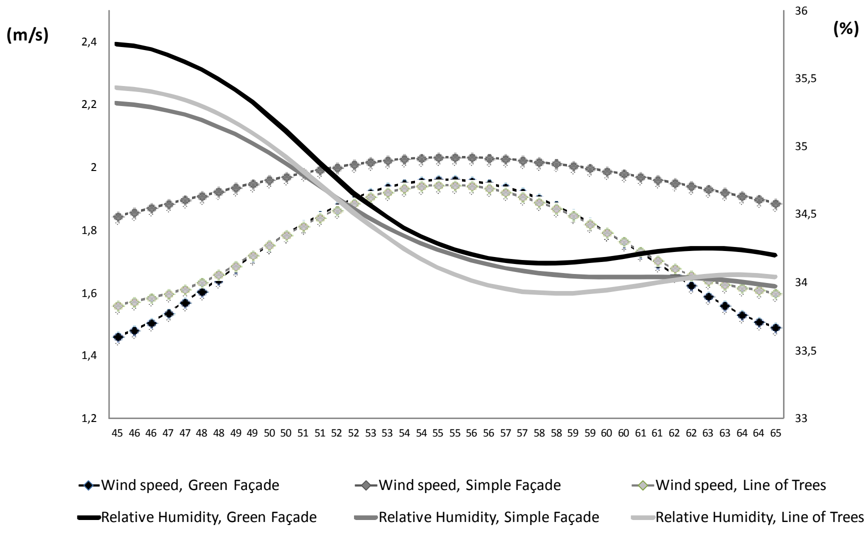

Figure 6. Comparison between wind velocity and relative humidity in a street with green façade, without it and considering a tree-lined street design in Madrid during summer time at 15:00 hours.

The decrease in temperature and moisture may be consequence of the green façade or because of the small streets have more shaded area.
New simulations have been performed, this time comparing the same street ratio varying the amount of vegetation with green façade, without it, and considering an urban tree-lined street. Figure 6 shows the relationship between parameters of wind speed and relative humidity in a cross section of the street at 15:00 hours during summer time. Best results are obtained in the area close to the green façade, that is: higher relative humidity and lower wind speed.

4 Life Cycle Assessment

The evaluation by life cycle assessment of environmental impacts due to the construction of the façade has been conducted during the project. For this analysis, it has been taken into account the manufacture of all the elements of the façade solution, that is, from the moment of extraction of raw materials up to the components of the façade are ready to be shipped to the construction site, that is to say, a cradle to gate analysis. There have been also included all stages of transport associated with the raw materials collection and their primary processing. For used fuels, there were taken into account the phases of extraction and transportation of oil to refinery and petroleum refining, the transportation to the distribution center, the transportation to end user and combustion in trucks with different payloads. In the case of electricity, it has been included the primary energy sources collection of different technologies of the Spanish mix in 2011, the electricity generation, transport and distribution to the end user. The inventory has been carried out with the cooperation of Intemper, S.L. who provided the specific activity data.
The functional unit basis of the study and results correspond to a $1m^2$ of envelope. The study was conducted to the future obtaining of an Environmental Product Declaration (EPD) according to ISO 14025 and ISO 21930 standards. The environmental impacts evaluated are abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion and photochemical ozone creation using the CML 2001 methodology according to prEN 15804 about sustainability of construction works. Table 1 shows the results of impacts evaluation.

Table 1: Results of the impact assessment for the life cycle of a $1m^2$ of SOS-Natura envelope.

Impact Category	Unit	Cradle to Gate
Abiotic Depletion Potential (ADP)	kg Sb-eq.	6.25E-01
Acidification Potential (AP)	kg SO_2-eq.	3.83E-01
Eutrophication Potential (EP)	kg PO_4^{-3}-eq.	6.84E-02
Global Warming Potential (GWP)	kg CO_2-eq.	3.02E+01
Ozone Layer Depletion Potential (ODP)	kg R11-eq.	6.09E-06
Photochemical Ozone Creation Potential (POCP)	kg Ethene-eq.	4.40E-02

Sensitivity analysis of the results allows suggesting improvements that would result in significant reductions of impacts. For instance, it would be necessary to seek for a new and closer supplier for vegetable fiber (used for the substratum where plants grow up) than the current one which is located in India. Another important impact reduction would have its origin in the mass reduction or replacement of the metal structure that serves as support for the different layers of the facade.

5 Conclusion

The SOS-Natura green façade system allows significant water savings compared to similar systems available on the market. It also offers a rapid execution of the construction work and reduces maintenance costs.
The living wall modules solution proposed tends to cool the ambient in summer conditions, with a difference of 5°C in comparison with other traditional façade solutions. It reduces the façade insulation thickness by almost 3 cm to meet the requirements of the Spanish Building code (CTE) in the city of Madrid.
Life Cycle Assessments methodology has been a useful tool to be used during the process of development and definition of a product. The fulfilled target was to quantify the real impact of materials and processed carried out in order to perform a responsible design.
As a conclusion, the benefit is general terms are to provide better indoor conditions and reduce energy consumption, particularly in summer conditions.

6 Citations

6.1 Acknowledgements

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